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Holocene and Modern Dune Morphology for the Magdalena Coastal Plain and Islands, Baja California Sur, Mexico

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ABSTRACT

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Moderate to well-defined Holocene and Recent dunes are present on the surface of the Magdalena coastal plain and on the top of sandy barrier islands of the Magdalena Lagoonal Complex in Baja California Sur, México. Early Holocene to Late Holocene aeolian deposits are mostly mega barchans (20 to 60 m high), linear dunes (10 m high), dune ridges (60 to 80 m high), nabkha dunes (5 to 10 m high), and a sand sheet (20 m high). Modern dunes are mostly crescentic dunes (transverse and meso barchans, 5 to 10 m in height), a dune ridge (40 m high), foredunes (5 m high), and nabkhas (1 to 5 m high). Holocene dunes are covered by semi-desertic vegetation. The abandoned vegetated old dune scarps and evidences of sea water land intrusion suggest a local older higher sea level, which probably occurred at global Holocene maximum sea level. Present erosional and depositional processes can be observed on the modern local coasts.

ADDITIONAL INDEX WORDS: *Holocene dunes, geomorphology, coastal erosion, sea water land intrusion, erosional and depositional processes.*

INTRODUCTION

Study Area Location

The study area is located on the west coast of Baja California Sur peninsula, between latitudes 26°00′, and 24°15′N and longitudes 112°15′, and 111°00′W (Figure 1). The study area is the surface of the Purísima-Iray Magdalena sedimentary basin physiographic geological subprovince. At 24°47 N, this basin extends 90 km from the coast inland becoming narrower to the northwest and the southwest. This subprovince shares its eastern boundary with the La Sierra de la Giganta province, which includes high mountains of volcanoclastic and volcanic rocks. The surface of the sedimentary basin includes the Magdalena coastal plain, which extends approximately 250 km along the coast. The submerged western margin of this province presents lagoons, estuaries, flooding flats, marshes, and rocky and sandy barrier islands. The group of these environments is locally named "Magdalena Lagoonal Complex".

General Statement

Where sand supply from shore sources produces extensive coastal dune deposits, these dunes can provide useful data concerning the history of coastal development. On the Pacific coast of Baja California Sur, Mexico, the large Magdalena coastal plain (Figure 1) exhibits aeolian deposits of different types, which morphologies have not previously been described. This is one of only two large coastal plains on the peninsular Pacific coast; the other is the Viscaino Plain in Central Baja California, which is also covered by stabilized and active dune fields. Our objectives in this study of the Magdalena area is to show the morphology of the different dune types emplaced on top of the Magdalena coastal plain (approximately 8,000 km^2) and to provide an interpretation of the Holocene climatic history base on the dunes.

The evolution and temporal dating of the emplacement of Magdalena coastal plain dunes was previously described by MURILLO *et al.* (1999). Episodic depositional events in the area began in the Late Wisconsin, Early Holocene with the development of linear and transverse dunes, which seem to have fully developed by 11 to 9 ka BP. In the middle Holocene, high transverse dunes were followed by the emplacement of lower transverse dunes and dune ridges. During the Late Holocene, one transverse dune field was emplaced (MURILLO *et al.,* 1999). The wind direction throughout the Holocene has varied, which has been inferred from dune orientation, being dominated by the northwesterly and west-northwesterly winds (MURILLO *et al.,* 1999). The main sediment sources of the aeolian deposits in the area are local rivers and the inner continental shelf (MURILLO *et al.,* in re-

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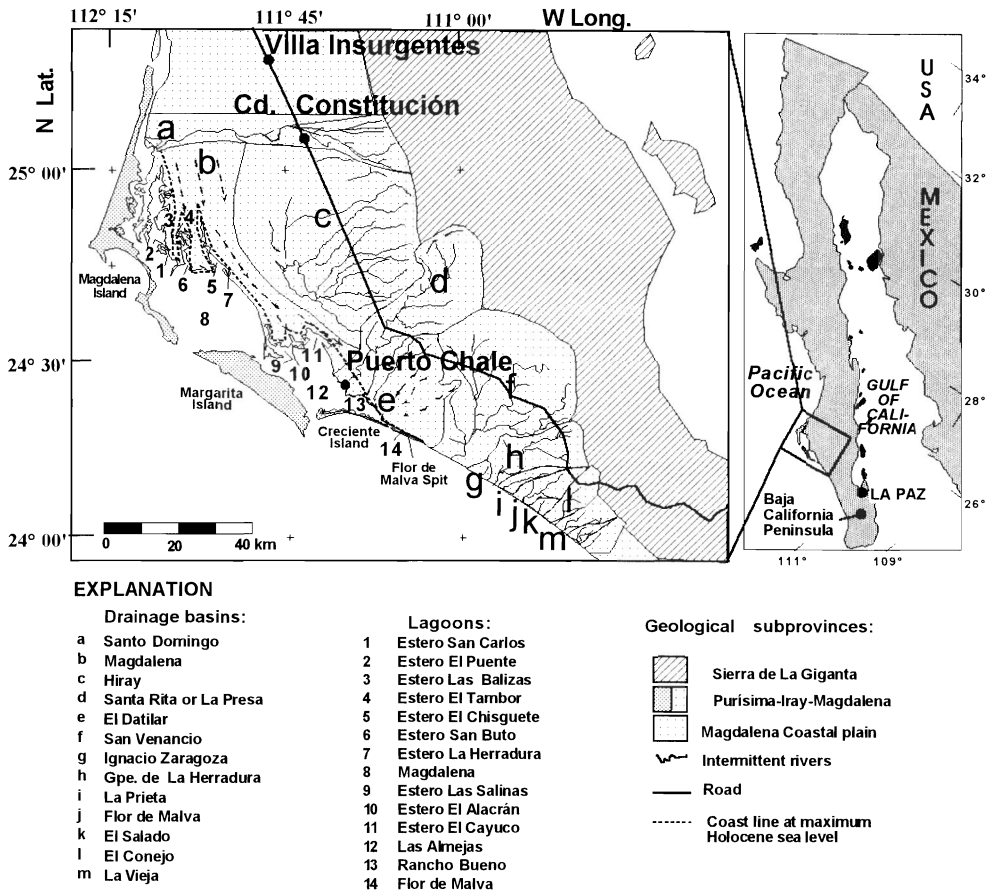


Figure 1. Location map and hydrologic map of the Magdalena Coastal Plain and Islands.

view). The morphology of some old dune fields is well preserved. Along the lagoonal coasts, dune erosion is observed which must be related to sea level stabilization. The principal drainage systems are the La Presa and San Venancio rivers (Figure 1), which originate in the western flank of the La Sierra de la Giganta Mountains and flow intermittently. The water discharge for the Hiray drainage basin (an endorheic basin) is into the Hiray flooding flat. The La Presa drainage basin pathway is through the Puerto Chale Estuary discharging into the Santa Marina Lagoon. El Datilar drainage basin water is mostly absorbed in the intermittent river beds, and some water discharges into the Santa Marina Lagoon. San Venancio drainage basin drains into the Pacific Ocean south of Flor de Malva Spit. In the Magdalena drainage basin and Las Almejas area the water is absorbed in the not well-defined intermittent streams. Sabkha deposits and estuaries are seen to invade old dune troughs. And, over the coastal plain dune fields have been mostly eroded by intermittent rivers, which most of which cut dunes transversely.

Methodology

The identification of dune types and boundaries was accomplished by analyzing aerial photographs of a scale 1:70,000 (I.N.E.G.I, 1973) by stereoscopic techniques; analyzing profiles obtained from topographic charts, scale 1:50,000 (I.N.E.G.I, 1983), from theodolite and GPS; and from ground-based sampling of the dunes. From these observations, geomorphic features were marked on topographic maps, scale 1: 50,000, and the resulting pattern was field checked during a reconnaissance flight which was made in July 1993. Oblique aerial photographs and video recordings were obtained. A figure was constructed, which shows the geomorphologic boundaries and types of dunes in the study area (Figure 2a), and the boundaries, local names of the dune field areas, and location of the profiles (Figure 2b). The identified dune types are based on the description of dune types by LANCASTER (1995), and COOKE *et al.* (1993).

Six profiles were taken from 1:50,000 scale topographic charts (Figure 3). These profiles helped in part to identify the boundaries between different dune types, and to show the morphology of the dunes. All the profiles cut perpendicularly through most of the dunes. Profile 1 begins on San Carlos port with a length of 45 km; profile 2 begins on the East coast of Magdalena lagoon with a length of 40 km; profile 3 begins on the outer coast of El Cisne spit with a length of 35 km; profile 4 begins on the East coast of the Las Almejas lagoon

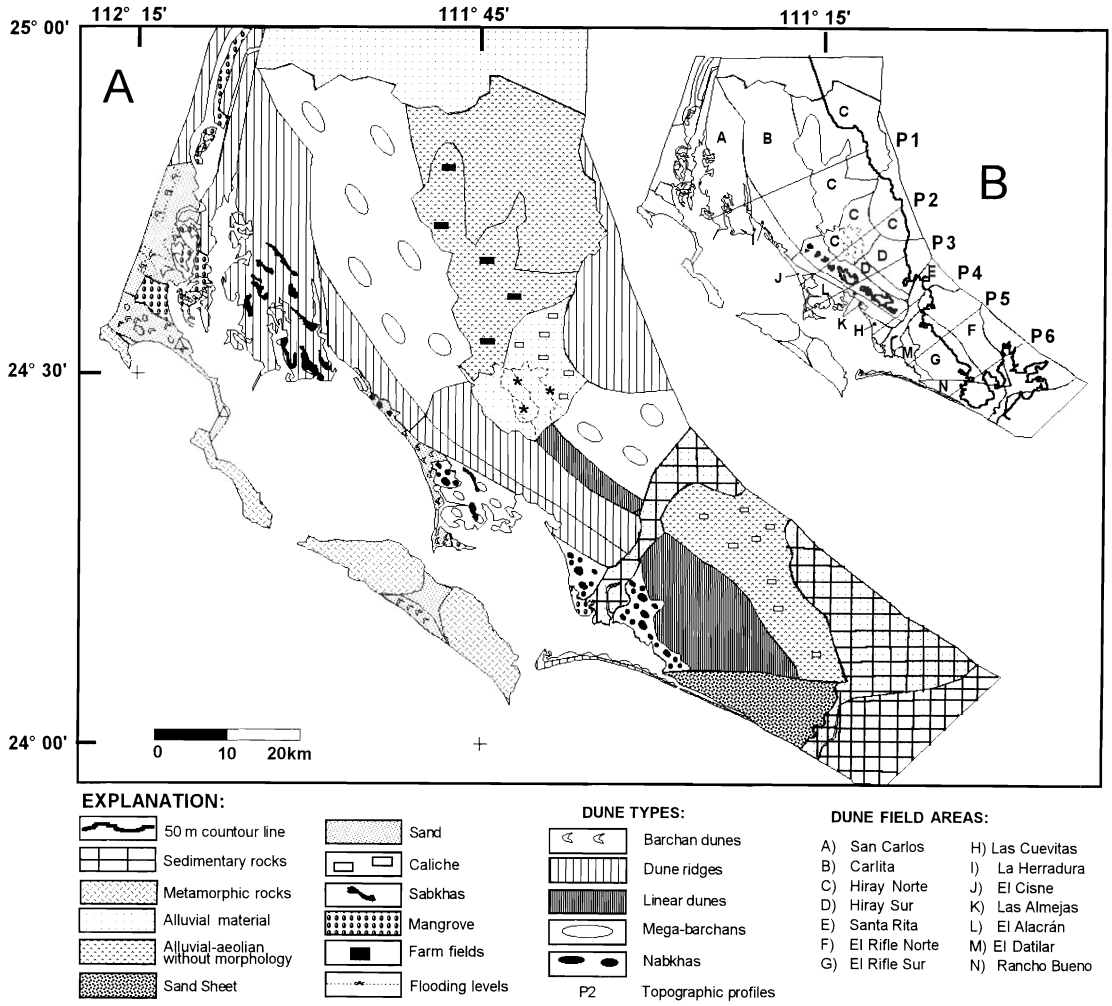


Figure 2. Geomorphologic map (A), location of dune field areas, and location of topographic profiles (B), within Magdalena Coastal Plain and Islands, Baja California Sur, México.

with a length of 20 km; profile 5 begins on the East coast of the Santa Marina lagoon with a length of 20 km; and profile 6 begins on the North coast of the Rancho Bueno lagoon with a length of 25 km. Profiles 7 and 8 were made over the linear dunes, using a theodolite and GPS Magellan satellite positioner (Figure 4).

DUNE DESCRIPTION

The characteristic morphology and large dimensions of each of the different dune types emplaced over the Magdalena coastal plain define sharp boundaries, which seem to be related to the following factors: time of the deposition of the aeolian material, availability of source material, and wind characteristics such as direction, intensity, and constancy. The most obvious features in the area are the presence of linear dunes, mega barchan dunes, dune ridges, foredunes, flooding flat areas, and sabkha deposits. For dune types that occupy large areas local names were assigned: San Carlos, Carlita, La Herradura, Las Almejas, Hiray Sur, El Alacrán, El Cisne, Las Cuevitas, El Datilar, El Rifle Sur, and Rancho Bueno. And also other local names were given to areas where sand sheets of aeolian material are mixed with alluvial material showing a not well-defined morphology, mostly flat surfaces, such as the Hiray Norte, Santa Rita, and the El Rifle Norte areas. The boundaries of these areas are shown in Figure 2b.

Dune Field Basement

In the Carlita dune field area (Figure 2b) the basement is a mixed deposit of old fluvial and aeolian material, which crops out in the Hiray Norte dune field area. In some dune field areas a thin, compact layer of flat blocks, boulders, cobbles and pebbles of caliche is found as the basement (approximately 50 cm thickness). Caliche crops out on the eastern boundary of linear dunes of El Rifle Sur dune field area, in river beds in the southeast portion of the Hiray flooding flat. It also crops out in a layer in a coastal scarp of the San Venancio intermittent river between the transverse dunes from

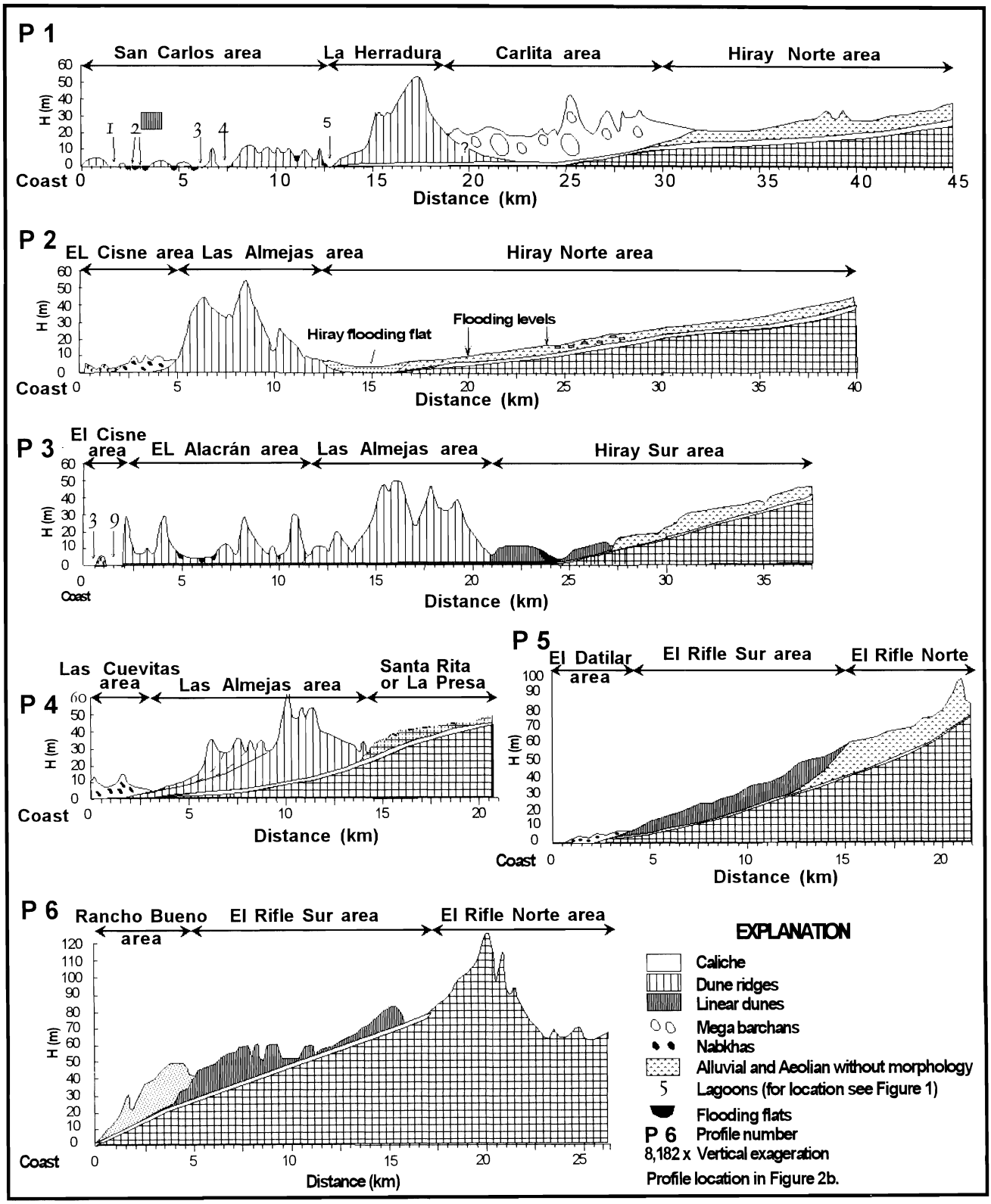


Figure 3. Topographic profiles 1 to 6, Magdalena Coastal Plain, Baja California Sur, México.

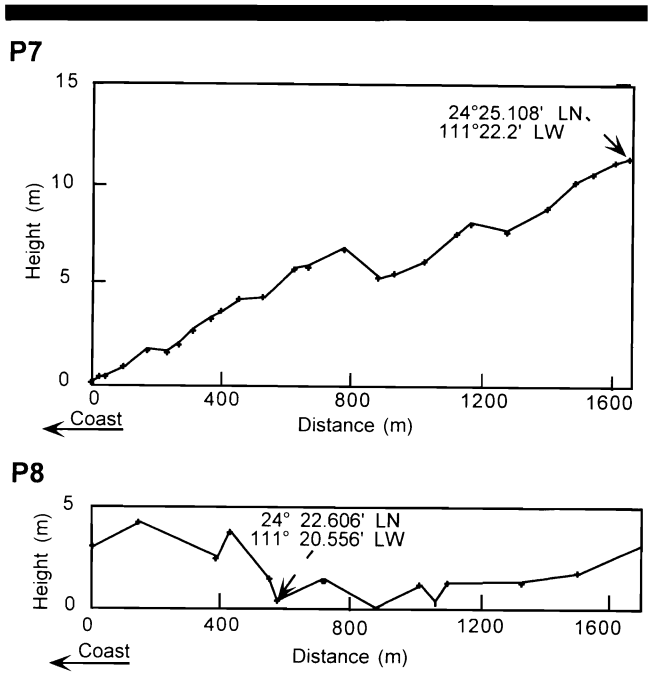


Figure 4. Topographic profiles 7 and 8, surveyed with theodolite, Magdalena Coastal Plain, Baja California Sur, México.

the Rancho Bueno area and the Tepetate Formation. From the literature most calcretes have formed in terrestrial conditions, and may be of shallow lacustrine or other sedimentary origin, although most are pedogenic in origin (HUTTON and DIXON, 1981). Caliche in this area may have formed during a Pleistocene low sea level period when the surface of the local marine sedimentary rocks of the Purísima-Iray sedimentary basin were exposed to weathering processes, or it may have been formed during and/or after the Holocene dune emplacement. No dates have been obtained for the various caliche outcrops.

Old Dune Vegetation

The following semi-arid vegetation is present on top of the Holocene aeolian deposits within the Magdalena coastal plain: Copalquín (Torote Blanco), Dipúa (Palo Verde), Slipper Plant (Candelilla), Ocotillo, Adam's Tree (Palo Adán), Cardón, Diamond Cholla (Cholla), Sour Pitaya (Pitaya Agria), Creeping Devil (Chirinola), Organ Pipe Cactus (Pitaya Dulce), Old Man Cactus (Garambullo), Nightshade (Mariola), Cardón Barbón, and Tree Yucca (Datilillo, Yuca) (ROBERTS, 1989). Some vegetation is dominant in one type of dune and some vegetation in other type of dunes, the distribution of the vegetation seems to be related to location and the sedimentary characteristics of dunes. The most dominant vegetation is Cardón, Palo Verde, Cholla and Ocotillo. For Recent active dunes shrub vegetation is mostly found in the trough of some dunes, and on the tops of nabkha dunes.

Description of Holocene dunes

Dune Ridges

San Carlos area. In the northwestern part of the study area, within the San Carlos area, aeolian deposits oriented northwest-southeast are present. The western limit of these deposits is on the coast, and the eastern limit is in contact with the mega barchan dunes of the Carlita area. Heights of the dunes are about 10 m, and the average distance between crests is 500 m. However, these are not regularly spaced. The western area seems to be the result of the coast line progradation, during which beach ridges were formed, and foredunes were deposited on the top. The eastern side shows more regular orientations, which may be related to dune reactivation. Dune reactivation is suggested from dates obtained in a core in this area (Early Holocene at the bottom of a core sample and Late Holocene at the top, MURILLO *et al.*, 1999). In this area either a previous dune field was covered with newer material or the previous dune surface was reactivated. Profile 1 (Figure 3) shows a topographic profile of this dune field. At the present time fresh scarps are present. Figure 5 shows an aerial photograph scale 1:70,000 of this area.

This dune field has been eroded and some of the troughs have developed tidal flats, on the coastal side, and others have developed sabkha deposits with saline crusts and pit deposits (the presence of pit deposits at different sites in this area suggest a good place to search for Late Holocene sea level fluctuations). The sabkhas within this area vary in size. They are generally between 1 to 5 km in length, and have widths of about 0.2 to 0.5 km. Closer to the coast some of them are aligned northwest-southeast. The orientation seems to be related to the original dune trough orientation. Between San Buto lagoon and canal Punta Banderitas the sabkhas are aligned north to south. Sabkhas are not surficially connected with sea water, but the sampled sabkhas contained salty water at about −20 cm in depth, at a distance of approximately 2km from the adjacent coast.

La Herradura area. A dune ridge located on the coast of the La Herradura area is about 20 to 30 m in height, it extends along the coast for about 7 km, dune blocks have collapsed onto the beach. In the topographic Profile 1 (Figure 3), a section of this dune ridge is shown. In a portion of the scarped dune ridge a layer of mollusk shells can be observed. To the west of the dune field an estuary is present, which must be the responsible agent of dune field erosion and lowland relief at the estuary sides. Figure 6 shows a coastal dune from this area.

Las Almejas area. In this dune field area, two dune ridges can be identified. One ridge is about 40 km in length, 4 km in width, and 60 to 80 m in height, and it has been eroded. The second dune ridge is closer to the coast and is located close to the northeast side of El Alacrán lagoon. The dimensions are 41 km in length by 2.5 km in width, and the dunes are 10 to 50 m in height. These dune ridges seem to be a foredune field. Between these ridges in the southern portion there is a depression about 11 km in length, and about 20 m in depth. These dune ridges are located in the central western part of the study area near the coast, and are limited to the north by mega barchan dunes from the Carlita area. The

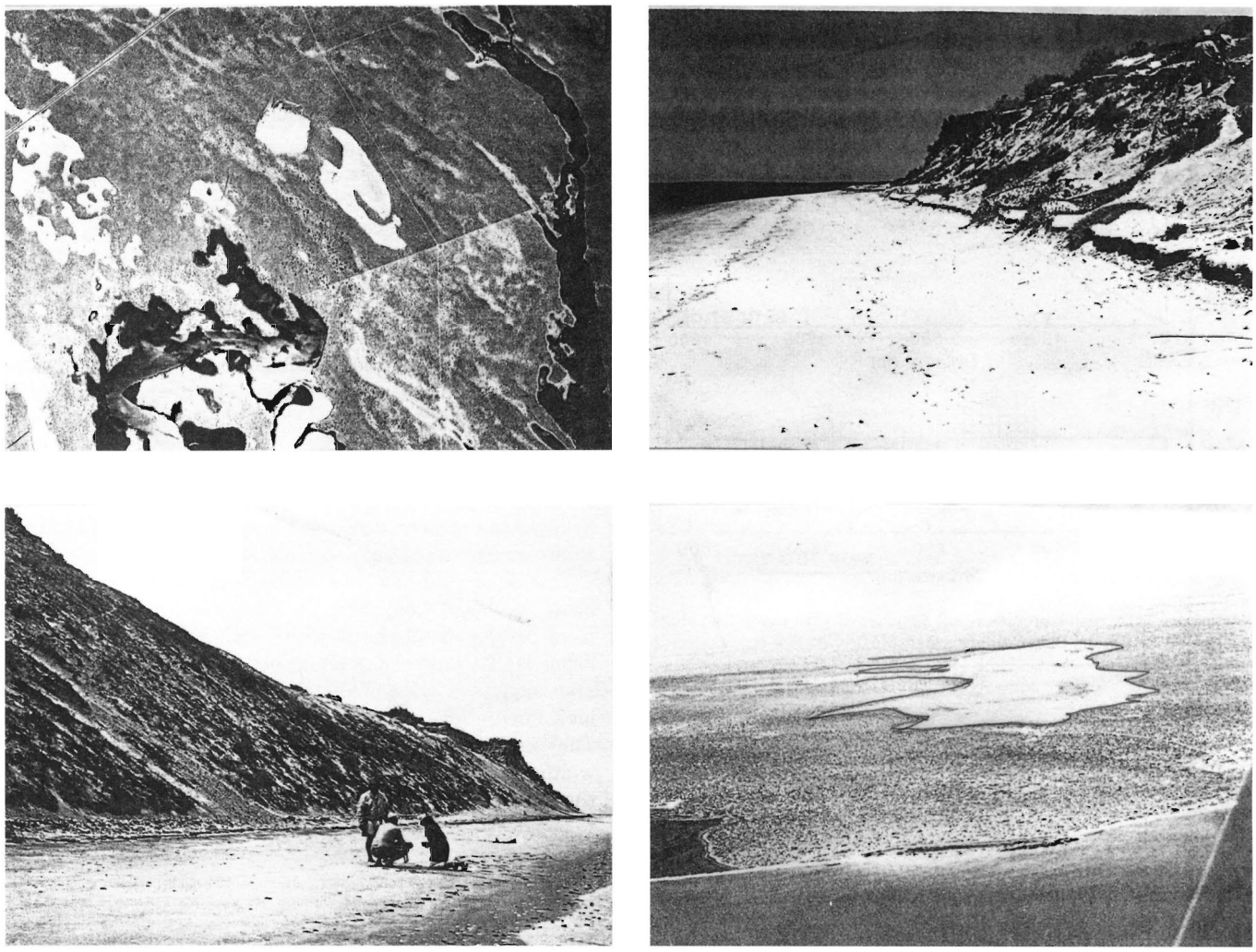


Figure 5. An aerial photograph (1:70,000) of dune ridges, within the San Carlos dune field area.

Figure 6. Aerial view of a coastal dune within the La Herradura dune field area.

Figure 7. Aerial view of a coastal dune within the El Alacrán dune field area.

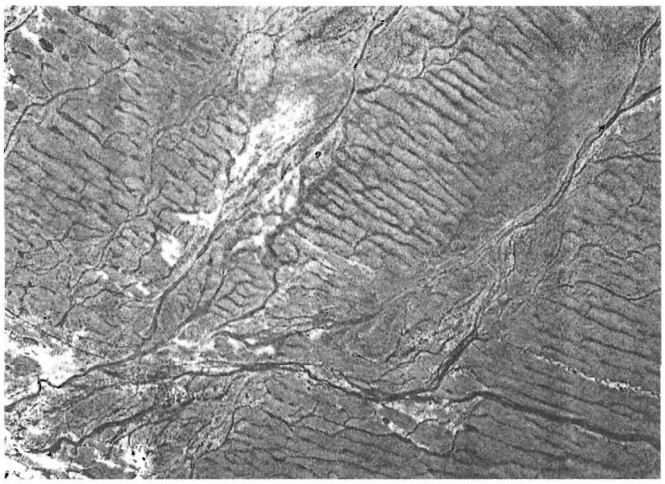
Figure 8. Aerial view of a sabkha within the El Alacrán dune field area.

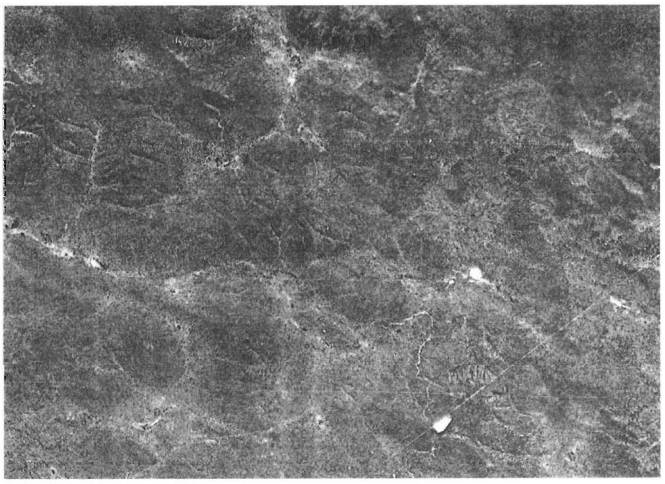
Eastern dune ridge is in sharp contact with a recent flooding flat which is part of the enclosed Hiray drainage basin. Dune ridges are limited to the southeast by linear dunes (Hiray Sur area), to the south are bounded by Pleistocene deltaic deposits of the La Presa drainage basin, to the southwest (in irregular sharp contact) are partly bounded by nabkhas of the Las Cuevitas area, and to the west are limited in part by probable mega-barchans from El Alacrán area. Profile 2 (Figure 3) shows a topographic section of these dune ridges. Dates obtained in the dune ridges are between 4.25 and 8 ka BP (MURILLO *et al.,* 1999).

El Alacrán area. Two sets of 30 to 40 m high dune ridges are present, which are oriented east-west and are separated by the Las Salinas tidal flat (Figure 7). This area is limited to the northeast by dune ridges from Las Almejas area; to the west by modern crescentic dunes from El Cisne area; and, to the south by the coast. A shell date obtained in this area gives an age of 8.22 ka BP (MURILLO *et al.,* 1999). The coastal areas exhibit large tidal flats, and coastal lagoons (El Cayuco, El Alacrán, and Salinas). These lagoons have smaller lagoons within them. In this area two sabkhas are present, the El Alacrán Norte sabkha is 3 km in length by 0.5 km in width (Figure 8), and the El Alacrán Sur sabkha is 1.5 km in length by 0.6 km in width. At the present coast in this area fresh scarps are present, which suggest Recent erosion. Profile 3 (Figure 3) shows a topographic section of this dune field.

Linear Dunes

Hiray Sur area. At the west side of this dune field area linear dunes are present. These are oriented northwest-





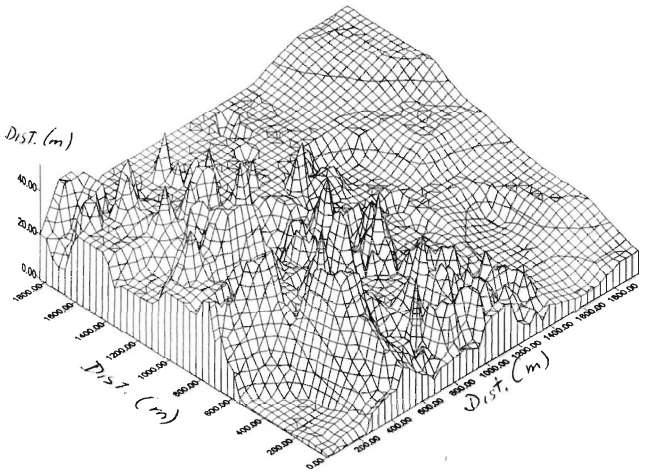


Figure 9. An aerial photograph (1:70,000) of linear dunes, within the El Rifle Sur dune field area.

Figure 10a. An aerial photograph (1:70,000) of the Carlita dune field area.

Figure 10b. A 3D plot of mega-barchan dunes within the Carlita dune field area.

Figure 11a. An aerial view of El Datilar dune field area.

southeast, are 10 m in height, and are spaced 500 m apart. To the east of the linear dunes an irregular and not well-defined morphology seems to be eroded barchans of 5 to 10 m in height. This area is dissected by intermittent streams, which drain into the Hiray flooding flat.

El Rifle Sur area. In this area, linear dunes are present. The area is 20 by 15 km in dimension. These dunes are limited to the west by the Santa Rita fluvial area, to the southeast by El Datilar area, to the southeast by the Rancho Bueno area, and to the northeast by the El Rifle Norte area. Linear dunes are preferentially oriented northwest-southeast in the northwestern area and shift to an east-west orientation in the southeastern area, they are covered by semi-desertic vegetation. Linear dunes are regularly spaced, they are 10 m in height, distances between crests vary from 140 to 450 m, an accurate length cannot be defined because intermittent streams are cutting dunes perpendicularly, however lengths of approximately 1 km to 2.8 km can be observed. Dunes present Y junctions which open mostly from the dominant resultant wind directions (wind was inferred from the dune orientation). Several dates were obtained in this dune field which vary from Middle to Late Holocene (MURILLO *et al.*, 1999). Late Holocene dates may represent dune reactivation. Figure 9 shows an aerial photograph (scale 1:70,000) of this dune field. Profiles 5 (Figure 3), 7 and 8 (Figure 4) show topographic sections of this dune field.

Barchan Dunes

Carlita area. In this area mega-barchan dunes are present, which are better defined in the southern part of this area. These dunes are limited to the East by alluvial and aeolian

deposits of the Hiray Norte area, to the west by dune ridges from the San Carlos area, and to the southwest by dune ridges from the La Herradura area. These dunes have been eroded and the original morphology is not well-defined, however it was possible to identify the gross morphology from study of aerial photographs. In the field along a local road, and along trails, crests and troughs can be observed. The northern area shows isolated barchans oriented northwest-southeast. Dunes in this area are up to 60 m in height. Profile 1 (Figure 3) shows a perpendicular section of this dune field, high relief may represent dune crests and low relief elevations may represent the lower part of the barchan flanks. The morphology in the northern part of this area is less well defined than in the southern area, which is probably because of the fluvial influence of the Santo Domingo river in the northern portion of the field. An aerial photo (scale 1:70,000) shows the morphology and orientation (northwest-southeast) of this dune field (Figure 10a). A 3D plot of this area is shown in Figure 10b. In this figure it can be observed, to the north of the plot, the contact between this dune field and the Hiray Norte area, and to the south its contact with a dune ridge from the La Herradura area.

Nabkhas

Las Cuevitas area. In this area dune distribution is patchy, 60% of the area is covered by Nabkha dunes which are 5 m in height and are covered by vegetation, along the coast, coastal dunes are 2 to 5 m in height. 40% of this area presents flooding flats or blowouts, which may have been triggered by a flooding event in the dunes. Profile 4 (Figure 3) shows a topographic section of this dune field and Figure 11b show an aerial view of this area. A shell date in a coastal dune from this area gives an age of 190 yr (aminoacid date, MURILLO *et al.,* 1999), however Nabkhas on land from this area must be older and are probably Late Holocene. In the coastal zone of this area fresh scarps expose the basement of this dune field, which is fluvial material from the deltaic system of the Santa Rita drainage basin.

El Datilar area. In this area, at the coast, modern low-relief foredunes are present, and in most of this area, old 5 m-high Nabkha dunes covered by vegetation and intervening flooding flats are present. The northern area of this dune field seems to have been part of the linear dunes of El Rifle Sur area, which were eroded, and thus the original morphology has been changed. El Datilar area in aerial view (Figure 11a, 11b) looks similar to Las Cuevitas area. This area is part of the deltaic system of the La Presa drainage basin, where the aeolian deposits partly overlie the frontal deltaic deposits, and in part, the linear dunes of the El Rifle Sur dune field area. Profile 5 (Figure 3) shows a topographic section of the dunes.

El Cisne area. In the middle eastern portion of this area, nabkha dunes of 1 to 5 m high are present, these have shrub vegetation on top (Figure 12).

Sand Sheet

Rancho Bueno area. From a reconnaissance aerial view and oblique aerial photographs, the morphology of this area looks like an irregular sand sheet covered by vegetation, with some barchans at the top of the northwest end of the dune field. In this sand sheet on the ground 20 m high elevations (probably transverse dunes) can be identified. This sand sheet is located in the southern part of the study area; the northern boundary is a sharp contact with linear dunes of the El Rifle Sur area, the southwestern part is bounded by the coast, and the eastern boundary is the contact with the San Venancio intermittent river. Along the coast this dune field presents inactive scarps (20 m in height) covered by vegetation. It is probable that after the Flor de Malva spit formed, the scarps were protected from erosion. Profile 6 (Figure 3) shows a cross section of this area. The basement of this area in the southern portion, is a thin, hard crust of caliche, which can be seen cropping out in the scarp of a meander of the San Venancio river. The meander exposes 10 to 15 m of sedimentary rocks from the Eocene Tepetate formation which is capped by a thin layer of caliche and aeolian deposits. In the northern portion of the sand sheet it appears that the basement is the linear dunes of El Rifle Sur area, which were previously emplaced.

Aeolian Deposits with Undefined Morphology

In the study area three large areas present evidences of old aeolian deposits (Pleistocene, TL date, around 100,000 years BP, MURILLO *et al.,* 1999) which were eroded and covered by fluvial deposits. After the emplacement of aeolian deposits in this area, the local climate changed to more humid and streams cut and modified the original aeolian sand morphology. The presence of the Hiray drainage basin seems to be the result of changes in local climate.

Hiray Norte area. Old aeolian material mixed with alluvial material crops out at the northeastern end of the study area. In the southern portion of this area a flooding flat (Hiray flooding flat, Figure 3, profile 2) is present, which is part of an endorheic drainage system within this area. The morphology of these deposits is of low relief, and they are distributed from along part of the base of the La Giganta mountains to the Hiray flooding flat. This area shows aeolian deposits oriented northwest-southeast. Eroded areas show a thin layer of caliche, which could be the dune basement or it may have formed after the dune emplacement. In Recent time part of this area has been used for agriculture purposes. These aeolian deposits seem to be, in part, the basement of the Holocene dunes of the Carlita and Las Almejas areas, which are located to the west of this area. Profiles 1 and 2 (Figure 3) show the gentle flat slope of this dune field area.

The Hiray flooding flat is blocked to the west by dune ridges from the Las Almejas area, which are up to 60 m in height. It contains silts and clays and is presently a grassland in aspect. The eastern side of the flooding flat shows evidence for at least three different water levels, which suggests that this area has been inundated at different periods of time in the recent geologic past. During oxygen isotopic stages 5e and 5d this flooding flat probably was a lagoon (Figure 3, profile 2).

Santa Rita area. This area is part of the Santa Rita drainage basin. In this area the La Presa intermittent river drains into the Las Almejas lagoon, and deltaic deposits are present. In

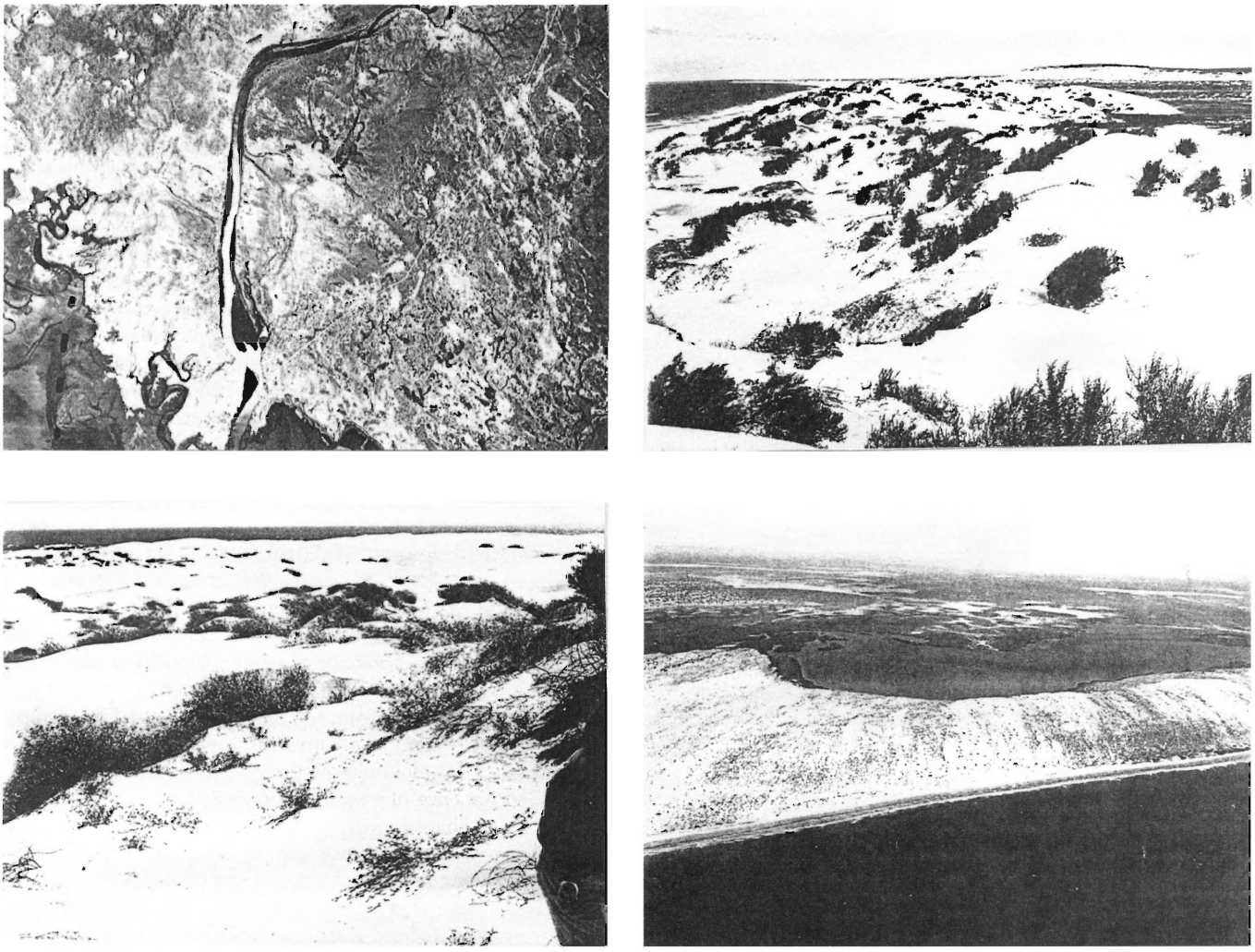


Figure 11b. An aerial photograph (1:70,000) of Las Cuevitas, Santa Rita, and El Datilar dune field areas.

Figure 12a. An aerial view of nabkha dunes within El Cisne dune field area.

Figure 12b. Barchan dunes within El Cisne dune field area.

Figure 12c. A dune ridge within El Cisne dune field area.

some areas, at the sides of the intermittent river, aeolian deposits are present which are part of dune field areas bordering this river. River material comes from in part from the erosion of the adjacent dune fields. The coastal side of this area is part of a delta, which at the present time in some areas along the coast, presents erosional and depositional features. Fresh scarps, and tidal flats with mangrove plants are present.

El Rifle Norte area. This area is in contact with the northern boundary of El Rifle Sur area. It appears that this area is part of the linear dunes of the El Rifle Sur area. In aerial photographs (scale 1:70,000), the dune morphology is not easily defined. Field reconnaissance identified low relief dunes, which are aligned similarly to the adjacent linear dunes from El Rifle Sur area. It appears that the dunes in this area were linear dunes that have been eroded and covered by fluvial material. The area is dissected by intermittent streams which at the base show in some areas a hard crust of caliche (probable dune basement). In the southern portion of this area marine sedimentary rocks crop out, as is shown in the topographic Profile 6 (Figure 3). In the northeastern area, west of the San Venancio river, very fine sand deposits are being eroded, which are probably lake deposits. In the sediment, snail shells have been found. The surface of these deposits is flat, has been eroded and shows low relief hills which are 1 m in height.

Description of Recent Active Dunes

El Cisne area. Within the El Cisne area two areas can be defined: the northern area, and the spit. In these areas different types of active dunes are present built on top. These

are oriented west-northwest, east-southeast. Shrub vegetation is mostly present at the top of dunes that are closer to the lagoonal coast, and mangrove is present on the estuary side. The northern area is limited to the east by the Las Almejas area, and the spit is bounded by the Las Salinas estuary. In the northern area, at the back of a beach (cusped), active nabkhas (Figure 12a) and nabkhas are present (Figure 12b). On top of part of the northern portion of the spit, an active dune ridge 40 m high is present (Figure 13c). Along the spit parallel ridges with dunes of not well-defined morphology are capped by shrub vegetation. These dunes are similar to the nabkha deposits but these are aligned west-northwest. On the southern portion of the spit a flat surface is present which shows active crescentic dunes of 5 to 10 m in height. The coastal area at the present time is depositional in character.

Flor de Malva spit. This spit is located in the southern portion of the study area. The inshore spit coast is part of the Rancho Bueno Lagoon. The spit seems to be protecting the old coastal scarps of the coast of the Rancho Bueno dune field area from erosion. Dunes that are cropping out on the spit do not show defined morphology, orientation, or pattern distribution; these are 5 to 10 meters high. Preferential wind directions seem not to be present.

Magdalena and Margarita islands. Crescentic dunes are present on the top of tombolos which connect rocky promontories of Magdalena and Margarita islands. Dunes from these islands, as within the El Cisne area, are the most extended recent transverse and barchan active dune fields in the study area, with dunes 5 to 10 m in height. Dune orientation (northwest-southeast) and morphology suggest resultant dominant northwesterly winds along the outer coast of these islands.

Description of Modern Lagoonal Coasts

The northern coast of the Magdalena Lagoon shows active dune scarps within the San Carlos area. The coastal sides of the La Herradura estuary show active and stabilized scarps covered by vegetation. The eastern side of Magdalena lagoon exhibits modern dunes of the El Cisne area. This coast at present time is in process of deposition, and a large spit within the El Cisne area is building. The northern coast of the Las Almejas Lagoon shows modern dune scarps within the El Alacrán area, and at the eastern coast of this lagoon modern deltaic scarps from the Santa Rita intermittent river are present (at the coastal side of Las Cuevitas area). At the sides of the river mouth depositional features such as tidal flats covered by mangrove are present. Within the El Datilar area to the southeast of Las Almejas Lagoon modern low relief dunes are present. To the west of the Las Almejas Lagoon along Margarita island coast narrow beaches are present, and to the south of the lagoon a sandy island (Creciente island) and a spit (Flor de Malva) are present.

FLOODING FLATS OR BLOWOUTS

In Las Cuevitas area flooding flats or blowouts are present, which are flat, elongated to irregular non-vegetated areas, surrounded by low relief vegetated dunes (Figures 11a and 11b). These hollows in many places are not oriented with the dominant wind direction, and are much larger than typical blowout dimensions. These are 50 to 700 m long, elongated features, with variable widths. Dominant sizes are approximately 200 m in length by 150 m in width, and a few of them are rounded. In a site 200 m from coast at −1.8 m depth, rock fragments are present, and at −2.80 m the water table is present. The ochre color on the surface probably is from concentrations of manganese (Dr. EVGEUNI SHUMILIN, *personal communication*).

PROBABLE OLD COAST LINE

A set of aerial photographs (scale 1:70,000, 1:1,000,000) show a morphological boundary which can be observed extending from Venancio river mouth (to the north of Santo Domingo (northern limit of the study area) to the northern limit of the Rancho Bueno area (in the southern part of the study area) (Figure 1). This extended boundary together with the presence of eroded Holocene dunes and abandoned inundated features (which appear that in the past to have been connected with Recent estuaries), seem to be evidences of a maximum local Holocene sea level. FARRAND (1965) suggests a maximum sea level at 7,000 ka BP.

From north to south of the study area it seems that at the maximum sea level the base of aeolian deposits from the San Carlos area were eroded and inundated. After sea level stabilization dune ridges from the San Carlos area were formed. The top and bottom of a core in this area show Late Pleistocene and Late Holocene ages respectively (MURILLO *et al.*, 1999). In La Herradura area at maximum sea level coastal scarps were formed with the formation of La Herradura estuary. At present time these scarps are covered by vegetation. Following along to the south it appears that at maximum sea level El Alacrán area was inundated by sea water and several estuaries were formed, estuaries which in Recent time are still present. Many inland evaporitic ponds including sabkha deposits seem to have been connected in the past with these Recent estuaries. In this area on the coastal side, fresh scarps are present. Passing to the south of the area there is a contact between dune ridges from Las Almejas area and nabkhas from Las Cuevitas area (Figure 11), which seems to show that during the maximum sea level the basement (fluvial deposits) of dunes from Las Cuevitas area was eroded, and then nabkha dunes were emplaced after sea level stabilization. Following to the south of the area there is an irregular boundary between regularly spaced linear dunes from El Rifle Sur area, and low relief nabkha dunes from El Datilar area. At maximum sea level part of the linear dunes were eroded, and after the sea level stabilization in the El Datilar area nabkha dunes were emplaced. Moving to the south, the morphological boundary seems to have been covered by a sand sheet within the El Rancho Bueno area. Coastal scarps in this area were perhaps formed during and/or after sea level stabilization. In Recent time the coastal scarps have been covered by vegetation and are being protected from farther erosion by the presence of a more Recent spit which is parallel to the coast of this area; the spit is part of the coast of the Rancho Bueno lagoon.

CONCLUSIONS

The main types of dunes within the Magdalena Coastal plain are Holocene mega-barchans, dune ridges, linear dunes, a sand sheet, and nabkha dunes. Recent dunes are dune ridges, barchans, transverse dunes, and foredunes, which are abundant on top of the barrier islands and along lagoonal coasts. The local distribution of these dunes is as follows: dune ridges within San Carlos area, La Herradura area, Las Almejas area, and El Alacrán area; linear dunes within Hiray Sur area, and El Rifle Sur area; mega-barchans within Carlita area; nabkha dunes within Las Cuevitas area, and El Datilar area; and a sand sheet within the Rancho Bueno area.

In the study area there are evidences that the local sea level in the past was higher than at present time, which could be related to the Holocene maximum sea level. The evidences are: a) there is an intermittent aligned geomorphic feature that starts from Venancio in the northern portion of the study area to the northern boundary of the Rancho Bueno area in the southern portion of the study area (this aligned feature may represent an old coast line developed at the maximum Holocene sea level, 7,000 yr BP); b) the presence of large evaporitic ponds and sabkha deposits, which seem to have been connected in the past with modern estuaries within the San Carlos and El Alacrán areas; c) the presence of a deltaic plain in Las Cuevitas area; d) the boundary between dune ridges from Las Almejas area and the nabkha dunes from Las Cuevitas areas; and e) the erosion of part of the linear dunes within El Rifle Sur area.

Along the coast with Holocene dunes there are evidences of modern erosional and depositional processes. Evidences of this are: the presence of active dune scarps along some portions of the modern lagoonal coasts and the development of the El Cisne spit on the eastern coast of the Magdalena lagoon. The presence of stabilized dune scarps covered by vegetation suggest abandoned scarps at falling sea level, which may happen during last sea level stabilization.

The geomorphic features of the area show at least three important events in the study area; First the emplacement of large dune fields, followed by coastal erosion and sea water land intrusion, probably in response to the maximum Holocene sea level, and lasting the erosional and depositional processes active along the modern coasts.

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LITERATURE CITED

COOK, R.U.; WARREN, A., and GOUDIE, A.S., 1993. *Desert Geomorphology.* London: University College, London Press; 526p.

FARRAND, W.R., 1965. The deglacial hemicycle. *Geologische Rundschau,* 54, 385–398.

INSTITUTO NACIONAL DE ESTADÍSTICA GEOGRAFÍA E INFORMÁTICA (I.N.E.G.I.), 1973. Aerial photographs of the west coast of Baja California Sur. Escala 1:70,000. Secretaría de Programación y Presupuesto, México.

INSTITUTO NACIONAL DE ESTADÍSTICA GEOGRAFÍA E INFORMÁTICA (I.N.E.G.I.)., 1983. Topographic charts. Scale 1:50,000. Secretaría de Programación y Presupuesto, México.

HUTTON, J.T. and DIXON, J.C., 1981. The chemistry and mineralogy of some South Australian calcretes and associated soft carbonates and their dolimitization, *Journal of the Geological Society of Australia,* 28, 71–79.

LANCASTER, N., 1995. *Geomorphology of Desert Dunes.* Richards, K., (ed.). London Routledge 290p.

MURILLO DE NAVA, J.M.; GORSLINE, D.S.; GOODFRIEND, G.A.; VLASOV, V.K., and CRUZ-OROZCO, R., 1999. Evidence of Holocene Climatic Changes from Aeolian Deposits in Baja California Sur, México. *Quaternary International,* V56(1), p. 141–154.

MURILLO DE NAVA, J.M.; GORSLINE, D.S., and ROBINSON, R.A., in review. Identification of Holocene Aeolian Sand Sources and Transport, Magdalena Coastal Plain and Lagoonal Complex, B.C.S., México.

ROBERTS, N.C., 1989. *Baja California plant field guide.* La Jolla: Natural History Publication, 309p.